# Pioneers

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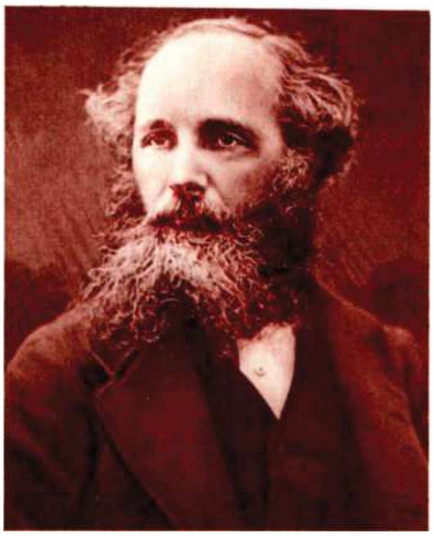
## 22. James Clerk Maxwell (1831-1879): Scottish laird and scientific genius.

But what is the little man there for? That was the question William Thomson, Lord Kelvin, asked as he peered into the eyepiece of one of Maxwell's optical experiments. The physical phenomenon described by Maxwell was evident, but so too was the figure of a little man – dancing. Baffled, Kelvin peered again. Why was he there? Maxwell's eyes twinkled as he answered, "Just for fun, Thomson".

Maxwell's sense of fun ran through his life, from his childhood paddling of a tub across a duck pond and tripping up the maid when she was carrying the tea tray, to spoofing his inaugural lecture as Cavendish Professor at Cambridge University. An inaugural professorial lecture is usually an affair of pomp and circumstance conducted before the university hierarchy. Maxwell so arranged the publicity for his lecture that it took place in an obscure lecture room before an audience of twenty or so undergraduates. A few days later, after a formal announcement, he gave the first of his undergraduate lectures. There in the front row were assembled the senior members of staff. To them and to his undergraduates, again with that



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mischievous twinkle in his eye, he very carefully explained the differences between the centigrade and Fahrenheit temperature scales.

Love him or hate him, Maxwell was a genius. Fully comprehend his electromagnetic theory and those famous equations or run a mile from them, they changed the world. They are at the foundation of modern physics and they are a major part of his legacy to us. From electromagnetic theory, paths can be traced to relativity and quantum theory as well as the more obvious path to radio. From quantum theory a path leads to semiconductors and so to modern electronics.

Though electromagnetic theory was Maxwell's supreme achievement, his other accomplishments were enough to secure him an important place in the history of science: colour perception, kinetic theory of gases and statistical mechanics, the theory of Saturn's rings, geometrical optics, photoelasticity and other topics. He wrote many elegant papers and a few books, including a two-volume "Treatise on Electricity and Magnetism" (1873) which the Encyclopaedia Britannica has described as "one of the most splendid monuments ever raised by the genius of a single individual".

### SHY AND DULL!

Maxwell belonged to the Scottish gentry, being descended from the Clerks of Penicuik, a family noted in Edinburgh from the seventeenth century. He was a skilled horseman and a good swimmer, and loved to read and write poetry. The Clerks had intermarried with the Maxwell family which owned a large estate at Glenlair in south-west Scotland. Maxwell's father, John Clerk, inherited that estate and took the name Maxwell to overcome a legal difficulty. Though a lawyer, he was interested in mechanics and attended meetings of the Royal Society of Edinburgh. Maxwell's mother, Frances Cay, died when he was eight. Both his parents were religious and Maxwell himself held a strong Christian faith.

Born in Edinburgh on 13 June, 1831, just eleven weeks after Faraday discovered electromagnetic induction, Maxwell spent his childhood at the family estate of Glenlair. At the age of ten he went to school at the Edinburgh Academy where he was at first regarded as shy and dull! Four years later, whilst still at school, he wrote his first published paper which duly appeared in the *Proceedings of the Royal Society of Edinburgh*.

After three years at Edinburgh University he moved to Cambridge, where he spent most of his time at Trinity College studying mathematics. Like the rest of us he faced trial by examination. In a letter written during his last term he expressed his attitude towards revision: "I am busy arranging everything so as to be able to express all distinctly so that examiners may be satisfied now and pupils edified hereafter. It is pleasant work and very strengthening but not nearly finished." Evidently his revision went well, for he sat his Tripos in January 1854 and came second. One wonders about the man who came first, E.J. Routh.

In 1856 Maxwell was appointed to the chair of natural philosophy at Marischal College, Aberdeen, where he spent three years before losing the position when the two colleges there were combined into one. As the junior of the two professors of natural philosophy, Maxwell was redundant.

Still, his three years at Aberdeen were notable for two achievements. Maxwell married the boss's daughter, Katherine Mary Dewar, whose father was principal of the college, and he won the Adams Prize of the University of Cambridge. This important prize was awarded every two years for the best essay on a given subject. The subject for 1857 was the motion of Saturn's rings, and a decision was sought between three hypotheses for the composition of the rings: solid, liquid/gas, or loose particles. Maxwell's mathematics led him to conclude that only the third possibility could yield the stability evident in the rings. This major contribution to astronomy set him amongst the leading researchers in mathematical physics.

With such a reputation he was not redundant for long. Soon he was appointed as a professor at King's College, London, but

**Fig.1. Maxwell, aged about 10, paddling across the duck pond at the Glenlair estate (sketched by his cousin Isabella Wedderburn).**

after five strenuous years there, whilst at the pinnacle of his career, Maxwell resigned and retreated to his country seat in Scotland.

Having suffered a severe illness, he adopted the relatively quiet life of a minor laird and took seriously the responsibilities of his position towards those whose welfare depended on his estate. However, he also continued his own studies, wrote his "Treatise on Electricity and Magnetism" and was an examiner for the Cambridge University examinations.

It was Cambridge University which lured him out of his "retirement" in March 1871 (when he was still not quite 40). The tempting offer was the newly established post of Professor of Experimental Physics, with the task of setting up from scratch a physics laboratory to be known as the Cavendish Laboratory. It was to be his final appointment. He tackled the job with relish and set that new teaching laboratory on its road to world renown as a research centre of the first rank. He even helped to design the building.

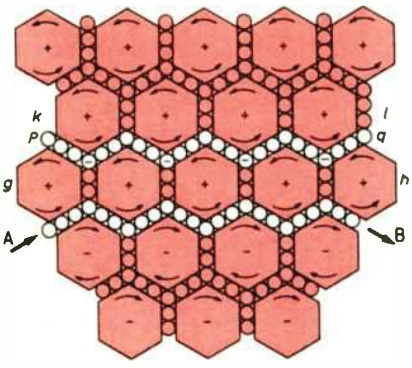
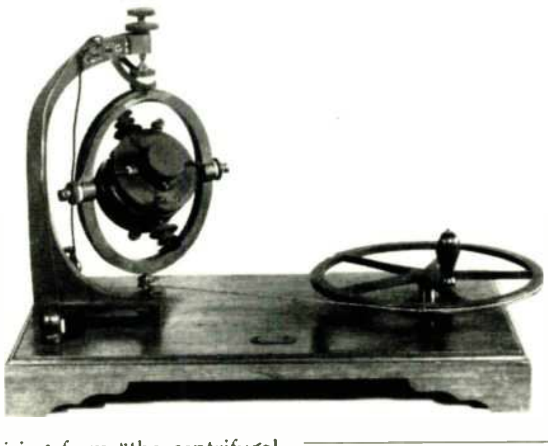



**Fig.2. Part of the model of the ether. AB are idle-wheel particles of electricity between the vortices (shown hexagonal). Lines of magnetic force enter and leave the plane of the paper. The kinetic energy of the vortex motion represents magnetic energy, and the force of the vortices on the particles represents electromotive force.**

## ELECTROMAGNETISM

To electrical engineers, Maxwell's greatest accomplishment was his electromagnetic theory. He was 24 years old, and had graduated about a year before, when his first paper on the subject, "On Faraday's Lines of Force", was published in 1855-56. He stated his intentions quite clearly, explaining that he was not trying to establish a physical theory but to show that "by a strict application of the ideas and methods of Faraday, the connexion of the very different orders of phenomena which he has discovered may be clearly placed before the mathematical mind". His "paper" contained about 25 000 words, almost half the length of a short novel today. To those who wanted a physical theory of electrodynamics he suggested the work of Wilhelm Weber.

His next publication on the subject came in a series of four parts issued from 1861-62, a mere 18 000 words this time. He assumed that magnetism depended on the existence of a tension in the direction of Faraday's lines of force and that the pressure was greater in the "equatorial than in the axial direction". This inequality of pressure was



explained as arising from "the centrifugal force of vortices or eddies in the medium having their axes in directions parallel to the lines of force". Since each vortex revolved in the same direction as its neighbours, a particle like an idle wheel was needed between them so as to avoid clashes at the edges of the vortices (Fig.2).

Whilst these ideas may seem unrelated to electromagnetic theory as we know it, Maxwell used them to construct a mathematical model of the ether using ideas from mechanics. Extending the model to electrostatics yielded the famous displacement current.

The mathematical analysis indicated that the electric and magnetic vectors are at right angles to one another and are propagated in air or vacuum with a velocity almost equal to the then known value for the velocity of light. "We can scarcely avoid the inference", Maxwell wrote, "that light consists in the transverse undulations of the same medium which is the cause of electric and magnetic phenomena."

A third paper, in 1864, added a further 20 000 or so words to his publications. It presented his theory of the ether and its relationship with electric and magnetic fields, stripped of the mechanical scaffolding with which it had been constructed. It introduced the terms "electromagnetic field" and "electromagnetic theory of light". In it he showed that a plane wave propagates with a velocity equal to the number of electrostatic units in one electromagnetic unit. Experimental values for this number, he said, agreed "sufficiently well" with the known value for the velocity of light. In a charming statement he noted that neither electricity nor magnetism had been used to measure the velocity of light, and that in the only known measurement of the ratio of the two systems of units "The only use made of light in the experiment was to see the instrument".

Obviously in the space available here a full account cannot be given of Maxwell's great work on electromagnetism. If you read his papers you may even have some difficulty in spotting those famous equations. The terminology is different from modern usage; and they were given in component form, not in the now commonly used vector calculus form. A full account of his work is given by Whittaker[1] and many shorter accounts are available. A glance through the pages of this magazine over the last couple of years reveals that his work on electromagnetism can still spark a lively debate[2].

## FIRST COLOUR PHOTOGRAPH

Less well known is Maxwell's work in other areas of science. Maxwell-Boltzmann statistics, for example, were derived to explain the kinetic theory of gases but are now frequently used in semiconductor theory.

Another major contribution to physics was his work on colour perception. It spanned about 20 years and was roughly contemporary with his electrical research. Whilst a student at Edinburgh, he and J.D. Forbes revived Thomas Young's idea that colour is a physiological effect of the eye and that there are three receptors. This ran contrary to the Newtonian belief in seven primary colours. (We all remember the Richard of York who gave battle in vain, don't we?)

Using spinning discs with coloured segments, Forbes and Maxwell showed experimentally that there are only three primary colours: red, blue and green. Maxwell also explained why the three primary colours and the three primary pigments are different, and he explained colour blindness. All that was great enough but, being a mathematician, Maxwell (now at Cambridge) went on to express his findings algebraically and created the science of quantitative colorimetry. He also probably projected the first colour photograph.

The last five years of Maxwell's life were partly devoted to editing the papers of Henry Cavendish. It was a period during which his wife endured a long and serious illness through which he nursed her whilst continuing to fulfil his professional duties. Eventually it became clear that he also was seriously ill. In June 1879 he left Cambridge for Scotland hoping the rest would help, but in October he was told he had only a month to live. Still caring for his bedridden wife, he returned to Cambridge to be under the care of his favourite doctor. He died of cancer on 5 November, 1879, aged 48.

**References**

1. E.T. Whittaker, A History of the Theories of Aether and Electricity. Nelson, London, 1951.
2. 'Joules Watt', Maxwell's e.m. theory revisited. *Electronics & Wireless World*, July 1987 page 697.

*Next in this series of pioneers of electrical communication: Walter Bruch, inventor of the PAL colour television system.*

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